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Presentation of the Neolithic type farming experiment conducted at the Parc de la Haute-Île (Neuilly-sur-Marne, France): implementation and results of cereal crops

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Abstract: This article presents implementation choices and initial results on crop yields and weed assemblages from a 3-year Neolithic-type agricultural experiment (2017-2020) at the "parc de la Haute-Île" (Department of Seine-Saint-Denis), about 20 km east of Paris (France). The project aimed to experiment the currently accepted farming system for the Early Neolithic in central Temperate Europe (ca. 5500-4900 cal BC), i.e., a system of winter or spring cereal cultivation, conducted on small permanent plots, whose fertility is maintained by a low input of organic amendment.

At the "Parc de la Haute-Île", work on the plots was minimal (no weeding, no irrigation, low fertiliser input) due to constraints related to labour and time availabilities of the experimental team. The plots were mainly cultivated with the two emblematic hulled wheats of the Linearbandkeramik period (LBK): emmer (*Triticum turgidum* subsp. *dicoccon*) and einkorn (*Triticum monococcum*). The initial state of the experimental site was a meadow surrounded by a wooded hedgerow and the initial soil had an inherent high fertility. The total area given over to the farming experiment was 180 m2 (31.5 m2 per plot). Each year, three plots were cultivated, either in monoculture or in maslin, i.e., cultivation of several cereal types on the same plot and subsequently harvested together. The annual cropping plans included one plot of cereals that had never been fertilized, another amended with animal manure (equivalent of 2 t/ha of animal manure), and another following the cultivation of a pulse crop (rotation). The aim was to evaluate the cereal yields following the different methods that were used (fertilization, seasonality), as well as the qualitative diversity of weed assemblages in the plots and in one processed einkorn subsample, sown in autumn and gathered low on the stem. The main questions underlying the experimental project are:

- Does low organic input cultivation without weed control benefit one or the other of the two-hulled wheats in the monoculture and maslin plots?
- Does soil fertilisation have a short-term effect on the yields of the hulled cereals?
- What is the composition of the wild flora present in the cultivated plots, what is its origin, is it representative of the cultivation methods?
- Does the weed flora found in the harvested lots after their treatment reflect the results from the agricultural plots?

At the "parc de la Haute-Île", emmer and einkorn competed with herbaceous weeds in the farming experiment with low labour input and low fertilization intensity. The yields for the two cereals show inter-annual but also intra-annual variabilities. Einkorn was the best performing cereal in both the monoculture and maslin plots. The average yield for einkorn is 1350 kg/ha (ratio 1:15) and 900 kg/ha (ratio 1:8,5) for emmer. The yield is always higher than 1:10 for einkorn regardless of when sowing took place and the fertilization methods. For emmer, the ratio is generally less than 1:10. Regarding sowing seasonality, the spring crop tested in year 1 (2018-2019) performed less well than the winter

crop for both taxa, with emmer even stopping its development during the agricultural season. On the unfertilized plot, there is a discontinuous evolution of yields between the test year (2017-2018) and year 2 (2019-2020) with the two cereals showing contrasting behaviours. For einkorn in the test year, the unfertilised plot delivered the highest yield (1:23) of the three years. On the five plots fertilized in monoculture, yields were not systematically higher than on the unfertilised plot (1:7) and even more than the vofertilized plots (1:12 and 1:17) yielded more than the unfertilized plot (1:7) and even more than the reference value of the test year (1:10). Emmer seems thus to respond somewhat better to shortterm fertilisation. These results contradict the current agronomic data that indicate a better productivity of emmer. This experiment leads us to assume that the better performance of einkorn during episodes of heavy rainfall could explain its preponderance on most of the LBK archaeological sites in Central European despite its supposed lower yield. Indeed, the experiment shows that currently, some varieties of einkorn can outperform emmer, several years in a row, under a low input winter cropping system with a soil with high inherent fertility.

36 herbaceous species were observed in the cereal plots. Most (n=25) were species identified in the meadow. At least 5 taxa may have originated in the meadow and/or initial seedlings and 2 taxa originated exclusively in the initial seedlings of the test year. The distribution by biological type shows 50% annuals (mostly winter annuals) and 50% perennials (without vegetative reproductive organs in majority). The high presence of perennials can be explained by the short duration of the experiment that did not favour annuals, and the low intensity of weeding. After threshing and winnowing, 10 taxa were identified to the species level in the einkorn stock. The distribution by biological type indicates 80% annuals, which are mostly winter annuals. Among the perennials, those without vegetative reproduction dominate. The ratio of annuals/perennials observed in the einkorn stock is thus not representative of what was observed on the plot. There is less diversity in the assemblage compared to what was recorded in the plots. Furthermore, winter annual weeds are over-represented compared to the ratio recorded in the plots, where perennials dominate. This could be explained by the fact that annuals, such as poppy (Papaver rhoeas) or brome (Bromus sp.), produce more seeds than perennials and are therefore more likely to be present in the samples. This result will have to be verified and explained when the entire harvest subsamples of the three experimental years are processed.

Keywords: Neolithic, temperate Europe, experimentation, hulled wheat, farming system, weed, cereal yield.

In order to promote the rich archaeological heritage discovered during the setting of the Parc de la Haute-Île Park in Neuilly-sur-Marne, the Departement of Seine-Saint-Denis has set up an archaeosite, within which a Neolithic area was opened in 2017 (Hoerni and Lafarge, 2018). The initial aim of this facility was to offer a mediation space for the general public and schoolchildren, with a reconstruction of a Neolithic house. An agricultural area was quickly added to this building for the purposes of experimental archaeology (figs. 1A and 1B). This approach, focused on the Neolithic period, was implemented in autumn 2017 thanks to collaboration between the Archaeological Heritage Office of the Department of Seine-SaintDenis and the UMR Archéozoologie, Archaeobotany: Societies, Practices and Environments (AASPE, MNHN-CNRS).

The aims of the experiment Haute-Île Park (2017-2020) were to test recent hypotheses concerning the methods and techniques implemented in the pioneer agricultural systems from Île-de-France and, more broadly, in north-western temperate Europe. The model currently accepted is a winter or spring cereal cropping system, carried out on small permanent plots, with fertility maintained by applying organic fertilisers (Bogaard, 2002a, 2004; Mueller-Bieniek et al., 2019). This model is based on data from archaeobotany, experimental agriculture and geochemistry. This article presents the archaeobotanical framework of the experiment, its implementation, including an explanation of the technical choices made and a preliminary analysis of the results concerning cereal yields and surveys of weed communities.



Fig. 1 – A, aerial photography of the "archéosite" taken in spring 2018 (test year) with location of the four experimental plots (*P*). Pulses and flax have just been sown on P3. The building of the Neolithic house is in progress (background: Géoportail); **B**, Location of the "parc de la Haute-Île" (map: A. Salavert); **C**, Location of the three main Neolithic-type experiments presented in the text (map background: Alexrk2, based on the database from naturalearthdata.com).

SITUATION AND OBJECTIVES OF THE EXPERIMENT

Archaeobotanical framework

What we know about plant food and agricultural processes of prehistoric societies is based essentially on the remains of cultivated plants seeds/fruits of wild plants, including weeds (i.e. plants that grow with crops without having been deliberately sown) from archaeological sites. In the Seine basin (Aisne and Seine valleys), archaeobotanical studies published on welldrained sites attributed to the Early Neolithic (Rubané/Linearbandkeramik, 5100-4900 cal. BC) are still few. The earliest data come from the Aisne valley, a tributary of the Oise (Bakels, 1984, 1995, 1999). In the Seine valley, preventive excavations carried out by the Institut national d'archéologie preventive (Inrap) have renewed our knowledge of the plant economy of the first farmers in Champagne (Toulemonde et al., 2021). However, as a general rule, plant macreo-remains are poorly preserved, allowing only a qualitative approach to agricultural diversity in this region for the early Neolithic period (Pernaud et al., 2004; Berrio, 2011). In addition, the role of harvested products (wild plants) and underground organs, such as roots and tubers in the diet in the Early Neolithic, but also in later periods, remains largely unknown (Dietsch-Sellami, 2007; Bouby et al., 2018; Cagnato et al. al., 2021; Hamon et al., 2021).

Cultivated plants and weeds

Seine basin sites delivered cereals and legumes typical of Linearbankeramik (LBK) of central and western temperate Europe, that is to say einkorn (*Triticum monococcum*), emmer (*T. turgidum* subsp. *dicoccon*), pea (*Pisum sativum*) and lentil (*Lens culinaris*) (Bakels, 1999, 2009; Kreuz, 2007; Salavert, 2011, 2017; Toulemonde *et al.*, 2021). Plant macro-remains assemblages of Seine valley, and more broadly of the Paris Basin, seem to be distinguished from the rest of LBK territory by the frequency of barley (*Hordeum vulgare*) and naked wheat (*Triticum aestivum sl/durum/turgidum*) (Bakels, 2009; Toulemonde *et al.*, 2021). Additional studies will nevertheless be necessary to clarify their status (weeds, cultivars) and their relative importance compared to the two emblematic hulled wheats of the regional's pioneering agricultural systems. Concerning oil plants, Champagne studies have shown the possible cultivation of opium poppy (*Papaver somniferum*) as early as the Early Neolithic (Salavert *et al.*, 2020; Toulemonde *et al.*, 2021).

Although listed in LBK sphere, Flax (*Linum usitatissimum*) is not identified in the Seine valley. The underrepresentation of oilseed plants, such as opium poppy and flax, is probably due to paucity of the archaeobotanical corpus combined with the fragility of seeds whose oilseed content does not favor conservation by carbonization. The method of cultivation, that is to say monoculture or maslin (that is to say several species sown, harvested and sometimes even transformed together), is difficult to highlight in archaeobotany because it is necessary to have closed contexts resulting directly from harvests, such as storage structures (Comet, 1992; Zech-Matterne, 2011; Toulemonde *et al.*, 2016). According to certain authors, the use of the mixture combining the two main cereals would be unlikely in LBK because both would not be mature synchronously, emmer preceding einkorn (Kreuz and Schäfer, 2011).

Mentions of crop weeds identified in the carpological (=archaeological plant macroremains) assemblages are used to understand the cultivated environment and aspects of the agricultural *chaine opératoire* such as cultivation methods and harvest processing. Indeed, the specific composition and diversity of weed flora in a field are influenced by the type of plant cultivated, seasonality of the crops, environmental factors (for example soil pH and edaphic humidity), or even organization of the landscape, depth of plowing and tillage intensity (Charles *et al.,* 1997; Fried *et al.,* 2008; Jones *et al.,* 2010). In addition, specific composition depends on the harvesting methods (under the ear, at the bottom of the stem) and post-harvest treatments (threshing, screening, winnowing). In the Seine basin, few

weeds' taxa are listed. The main taxa, as throughout LBK territory, are fat-hen *(Chenopodium album)*, wild buckwheat *(Fallopia convolvulus)*, bromes *(Bromus* spp.), lampsana *(Lapsana communis)* and even cleavers *(Galium* spp.) (Bakels, 1999).

Linearbandkeramik agricultural system

Slash-and-burn agriculture was one of the first agrarian systems proposed to explain the rapid expansion of Neolithic migration into a forested area in central Europe (Clark, 1952; Isaaki-dou, 2011). This system consists of cultivating a plot in a forest environment, after having cleared it and burned it. The burned organic matter then provides nutrients that would improve agricultural yields. The hypothesis of the practice of slash-and-burn during Early Neolithic in temperate Europe has nevertheless been reassessed since the 1980s. The main arguments are that this system would be based on an inappropriate analogy with historical practices in northern Europe, and that amended permanent fields could offer high cereal yields over several consecutive years (Rowley-Conwy,1981).

Hypotheses concerning LBK farming system, including methods to maintain soil fertility, have largely been renewed over the past twenty years (Bogaard, 2002a, 2004; Kreuz, 2007; Kreuz and Schäfer, 2011; Bogaard *and al.*, 2013). According to this work which combines carpological analysis of substantial sets of archaeological weeds and nitrogen isotopic composition (δ 15N) of cereals, the first farmers in temperate Europe would have practiced intensive cultivation of small agricultural areas without shifting and at household level. The model intensity includes a significant labor factor per unit area, called "intensive *labor input" in* Anglo-American literature (Bogaard, 2005). This intense work includes fields amendment through manuring, tillage and regular weeding after sowing.

Seasonality of sowing (autumn and/or spring) deduced on the basis of biological types of archaeological weeds, such as their germination period, is still much debated for the Neolithic (e.g. Bogaard, 2002b; Kreuz and Schäfer, 2011). This agricultural model would be combined with breeding of small herds near habitats (Bogaard, 2005).

NEOLITHIC AGRICULTURAL EXPERIMENTATION IN TEMPERATE CLIMATE

State of the heart of experimental work

Interpretations of archaeobotanical results are based on work and references from current phytosociology and agronomy, historical and ethnological sources. For example, current weed ecology, or cereal residues composition from the different processing stages (threshing, winnowing) as observed in ethnology, support the interpretation of archaeological plant assemblages (Bouby, 2000). However, today, models of subsistence farming (*agriculture vivrière*) integrating cereal cultivation, and developing in ecological and socioeconomic contexts comparable to those of the Neolithic period, are non-existent in temperate Europe. To overcome the absence of current and sub-current comparisons, farming experiments make it possible to validate research hypotheses based on archaeological and archaeobotanical material, to evaluate feasibility of proposed *Chaine opératoire*, and to open avenues of reflection, potentially new, around the first European farming systems (Lüning *et al.*, 1980). They are capable of producing benchmarks for the different stages of agricultural *Chaine opératoire* by controlling as many climatic, technical and cultural parameters as possible.

To our knowledge, three Neolithic agricultural experimentation projects have been developed (fig. 1C), in a humid temperate oceanic climate according to the Köppen-Geiger classification, that is to say without dry season and with mild summers (Lüning *et al.*, 1980; Firmin, 1984; Meurers-Balke and Lüning, 1990; Peel *et al.*, 2007; Ehr-mann *et al.*, 2014; Rösch *et al.*, 2017). Implemented over a variable duration, these projects mainly tested slash-and-burn model, with or without shifting (itinerance) which was the farming system

favored by archaeologists in the 1980s for the Early Neolithic (Rowley-Conwy, 1981). In the case of Chassemy (1982-1983) and Hambach (1979-1984), the burning was carried out each year without moving the cultivated lots, using plant elements harvested nearby and placed on the plots. In the case of Forchtenberg's long-term experiment (1998-2012), crops were moved to another area having undergone the same treatment (tree felling, then burning). Forest regeneration then took place on the old plots left fallow. Although autumn sowing could be implemented in this experimental work, spring sowing was favored, particularly in Hambach (tab. 1).

At least three other experiments should be reported. The Butser Ancient Farm project (19732007) in Hampshire (England) had the initial aim of better understanding the agricultural economy of the Second Iron Age and early Roman period (400 BC-400 AD), and included emmer in crops (Reynolds, 1977, 1979, 1999). Two other experiments in Neolithic farming were carried out in a more continental climate in Czech Republic in the 1980s (Kazdová, 1983; Beranova, 1993).

Objectives and limits of the Haute-Île Park experiment

The farming experiment carried out on the Archaeosite aimed to test the cultivation of small permanent fields, by applying different methods of fertilization and harvesting, and with minimal labor intensity, that is to say no weeding after sowing, no irrigation and a low supply of manure. This agricultural system has, as far as we know, never been tested in western temperate Europe.

Like the experimental projects cited above, the Haute-Île Park experiment did not aim to scrupulously reproduce the appearance of a Neolithic field (Lüning *et al.*, 1980). The team involved in the experimental project did not have practical skills in cereal agriculture. The working time devoted to field works was limited, compared to the time that Neolithic men and women could probably devote to their cultivated plots. For this last reason, frequent manual weeding and a high application of manure were not possible.

Furthermore, at Haute-Île Park, the cultivated area is part of an environmental framework including the surrounding vegetation, topography and hydrography, which has changed significantly since the beginning of recent Atlantic. For example, weed flora is not only composed only of native type taxa and archaeophytes, that is to say, that arrived with the introduction of cereals from the Near East, but also of neophyte species. The latter correspond to plants arriving from the 16th century such as datura *(Datura stramonium)* then naturalized in Europe (Brun, 2008). In addition, the cultivated plots constituted a place of mediation and research, and not living space, which is in itself a limiting factor, for example, for the development of weed flora linked to the anthropization of the environment in the case of subsistence cereal cultivation (Rösch *et al.,* 2017).

Finally, several unforeseeable constraints forced us to moderate our scientific ambitions. On the one and, access to the Haute-Île Park was not possible in spring 2020 due to travel restrictions during health (Covid) crisis. Surveys of weed flora on the plots and spring sowing of cereals and legumes could therefore not be carried out in year 2 (2019-2020). The field work starting in fall 2020 and the rotation planned for year 3 (2020-2021) could not be anticipated. The experiment, originally planned for five agricultural years, had to be stopped earlier. Thus, the relatively short duration of the experiment (2017-2020) offers a reduced time window to test plot fertilization methods and observe the dynamics of weeds assemblages over a long term. On the other hand, the loss of harvests from the maslin plot carried out in year 1, at its storage location in the Haute-Île Park, limits the analysis of the yield and behavior of hulled cereals cultivated with this method.

The experiment nevertheless made it possible to acquire standards for the yields of monoculture plots over three consecutive years, as well as the composition of weed flora on the cereal plots and after their processing (threshing, sieving) for two successive years. The main questions underlying the experimental project are:

- Does low organic input cultivation without weeding benefit one or other of the two types of wheat grown in monoculture and maslin plots?

- Does soil fertilisation have an effect on the yields of the two hulled cereals in the short term?

- What is the composition of the wild flora present in the in cultivated plots? What is its origin, is it representative of cultivation methods? Does weed flora found in harvested batches after processing reflect the diversity found in the plots?

The more general aim of the Haute-Île Park experiment is to provide new elements for to interpret the archaeobotanical assemblages, particularly the choice of hulled cereals (emmer and einkorn) and methods for interpreting floristic assemblages of carpological assemblages in the frame of cereal cultivation with minimal fertilisation and minimum tillage.

IMPLEMENTATION OF THE EXPERIMENT

Experimental protocol was prepared in advance thanks to archaeobotanical and archaeological literature and experimental work that has already been in western temperate Europe (see above). The experiment took place over three agricultural years, i.e., from autumn sowing to summer harvesting, including a test year (2017-2018). The purpose of the test year was to try out different sowing methods, familiarise the team with farming work and evaluate the time required for each task, i.e., soil preparation, soming, harvesting and crop monitoring. Over the next two years (2018-2019 and 2019-2020), two crop rotations were experimented including two fertilisation methods: amendment with animal manure (manuring) and rotation with legumes.

To optimise the working time dedicated to the experiment, only cereal plots were used in the research axes.

Initial state of the experimental site

The initial state of the site is a grassy clearing, rich in grasses, clovers and other meadow plants, grazed by the park's Solognot sheep (fig. 2A). The clearing is surrounded by woodland. The woody taxa making up the edge are mainly rosaceous plants (*Prunus* spp., *Rubus* spp., *Crataegus...*), willows (*Salix caprea*) and maples (*Acer* spp.). The clearing has not been used for farming since the 19th century. Soil analysis carried out by the *Laboratoire d'analyses microbiologiques* showed soil compaction caused by archaeological work carried out in the clearing in the 2000s and an invasion of the area by goosefoot and thistle-type plants (Bourguignon et al., 2016). The soil texture is silty-sandy on the surface, with localised hydromorphy at depth. PH is basic (>8.2). The soil surface horizon (<60 cm) has a good organic matter content, high nitrogen and potassium content, and a large earthworm population. The initial state of the site, in terms of granulometry, chemical and biological structure as well as floristic diversity was conditioned by the rearrangements linked to the archaeological activities of a part, and for its use, dedicated for ten years, on the grazing of sheep on the other hand. The initial soil is endowed of high inherent fertility.

Seeds and annual rotation

The plants chosen are the two emblematic hulled wheats of LBK period, emmer (*Triticum turgidum* subsp *dicoccon*) and einkorn (*Triticum monococcum*) (fig. 3). The choice of two legumes, pea (Pisum sativum) and lentil (Lens culinaris) was motivated by the wish to experiment rotation with legumes as a method of fertilization. Moreover, it was about presenting the diversity of cultivated plants by the pioneer farmers of the Seine basin in the framework of archaeosite mediation activities. For this last reason, an oilseed plant, flax (*Linum usitatissimum*), was integrated into the rotation in addition to the legumes. For the first sowings of the test year in 2017, the selected varieties were given by J.-F. Berthellot of

Ferme du Roc in Lot-et-Garonne (France). A variety of emmer (amidonnier de Soubise) and a variety of einkorn (engrain noir de Turquie) were each sown in monoculture. Two varieties of emmer and two varieties of einkorn were sown in maslin.

| Site | Chassemy | Hambacher Forst | Forchtengberg | Parc de la Haute-Île | | |
|--|---|--|--|---|--|--|
| Années | 1982-1983 | 1979-1984 | 1998-2012 | 2017-2020 | | |
| Localisation | Localisation Vallée de l'Aisne (France) | | Baden-Württemberg (Allemagne) | Seine-Saint-Denis (France) | | |
| Milieu | Milieu Dépôts alluvionnaires de la Vesle, texture sableuse acide, faible teneur en matière organique | | Plaine légèrement vallonnée. Sols limoneux. | Dans paléoméandre de la Marne, Sols limono-sableux. | | |
| Altitude | 69 m | 76 m | 76 m 320 m | | | |
| Cumul moyen des précipitations/ an | 730 mm | 989 mm | 860 mm | 639 mm | | |
| Température moyenne/an | ane/an 11°C | | 9°C | 14°C | | |
| Etat initial du terrain expérimental | Taillis sous futaie peu riche, chêne pédonculé et bouleau | Sylviculture depuis plusieurs siècles. Forêt fermée. Chênaie-charmaie | Forêt mixte décidue avec haute diversité taxono- mique. Chênaie-charmaie et hêtraie-chênaie | Clairière sur une butte entourée d'une zone boisée | | |
| Mode de préparation des sols | Brûlis d'un apport d'éléments végétaux + houe | Brûlis + houe rotative | Brûlis, sans brûlis, et sans labour | Aération superficielle. Pas de brûlis. | | |
| Outils utilisés Plantoir (morceau de bois), bâton à fouir, houe | | Charrue en bois, engin mo- torisé. Crochets à manches courts et à manche long. | Bâton en bois, hâche néolithique | Aérobêche, houe métallique, crochets à manche court | | |
| Espèces semées | Espèces semées Triticum aestivum/compactum (dit amidonnier vêtu dans Fimin 1984, p.97), Hordeum vulgare (escourgeon) var. nudum et variété vêtue, Triticum compactum | | T. aestivum, T. turgidum subsp. dicoccon, Hordeum hexastichon | Triticum turgidum subsp. dicoccon, T. monococcum, Pisum sativum, Lens culinaris, Linum usitatissimum | | |
| Méthode de semis | Sillon, poquet | Sillon | Poquet | Poquet, à la volée (année test), sillons | | |
| Taille parcelle × nombre de parcelles | 25 m² × 5 | <mark>9 m² × 20</mark> | 90 m² × 34 | 31,5 m² × 4 | | |
| Saisonnalité | Printemps (année 1 : 1982) et automne (année 2 : 1982-1983) | Printemps 1979-1984 | Printemps (blé nu), hiver et printemps (amidonnier et orges) | Hiver et printemps (2018-2019) | | |
| Désherbage | Oui et non | Oui et non | Oui <mark>et no</mark> n | Non | | |
| Références principales Firmin 1984, 1991 | | Lüning <i>et al.</i> , 1980 ; Meurers-Balke et Lüning, 1990 ; Bogaard, 2002 | Rösch et al., 2002, 2011, 2017 ; Ehrmann et al., 2007 | | | |

Table 1 – Synthetic presentation of the Neolithic-type experiments in Europe in humid oceanic temperate climate.

The total area devoted to agricultural experimentation is 180 m2. A strip of two meters wide was planned at the interface of the plots. The surface of each of the four plots, called P1 to P4, is of 31.5 m2 (fig. 1A, tab. 2). Each year, three plots were dedicated to the cultivation of hulled cereals, and a plot for sowing flax, peas and lentils, for a third of the surface each. During the test year, the soils were not fertilized due to their high inherent fertility. The cereal plots were cultivated either in monoculture of emmer (P1) and einkorn (P2), or in maslin (P4). Over the next two years, plans rotation have planned a plot of cereals without any fertilization (always P1), another manured (winter and spring sowing) and another succeeding a legume crop (fig. 2B). The complete rotation including the cultivation of cereals without inputs (test year), followed by cultivation of legumes (year 1) then a cereal crop with manuring (year 2) could be accomplished only on one plot (P3). During the three experimental years, a total of 2,260 kg of spikelets was been sown, all species and varieties combined (tab. 2).



Fig. 2 – A, the initial clearing, June 30, 2017; B, overview of the crop rotation of year 1 (2018-2019) and location of the plots. Pulses are sown in P4, flax is in flower (photos: A. Salavert).

Tools

There are no clearly identified tools as having been used for the preparation of soils such as its loosening, on LBK sites. No direct evidence (faunal bone pathology, iconography) or indirect animal traction (e.g. travois) is attested in the Early Neolithic in Île-de-France probably due to not favorable taphonomic conditions. The plough and the ard do not seem appear before the middle of the 4th millennium in Europe (Pétrequin et al., 2006).

During the experiments of Hambach and Chassemy, a replica of a wooden hooked hoe, similar to the maple pick discovered in a well in Erkelenz-Kückhoven in Germany (Weiner, 1992; Broes and Bosquet, 2007: fig. 3) was tested on previously loosened soil by the practice of burning, without effectiveness (Lüning et al., 1980; Firmin, 1984; Bakels, 2009). On the archaeosite, experimental hook hoes also were used during the test year. This experience was conclusive due to the difficulty of penetration of the tool in the ground, probably due to the angle of attack of its hook (60°), the lightness of the tool and its short handle which is not intended for soil working. This is especially the case during the test year because the surface

to be prepared had a high-density root. Burning could not be used to help to the initial preparation of the ground due to constraints security issues linked to the status of the Haute-Île Park (site of Natura 2000 network in urban areas). The technical choice was therefore oriented towards the broadfork (U-fork, *grelinette*, *biobêche*) which we suppose act within the limits of Neolithic agricultural tools capabilities in wood or stone. The Broadfork is a tool with easy-to-handle metal teeth, which allows to decompact and aerate surface soil without returning the earth (fig. 4A).



Fig. 3 – A, black einkorn (Triticum monococcum); B, emmer (Triticum turgidum subsp. dicoccon); C, two varieties of einkorn and emmer (yellow and black) sown in maslin (photos: A. Salavert).

The preparation of the soil of the plots therefore consisted of (1) decompact the surface layer of the soil by breaking the roots of herbaceous plants using a broadfork, (2) break with a metal hoe the clods of grassy land obtained after the passage of the broadfork. This protocol was most often performed twice on each cereal plot. The soil preparation work turned out to be laborious, particularly on all plots of the test year as well as on the plot cultivated without fertilization (P1) the following two years. In fact, the rotation with legumes loosens the soil and considerably facilitates its preparation before sowing.

Fertilisation

Analysis of carbon isotopic composition (δ 13C) and nitrogen (δ 15N) from the crop seeds, mainly cereals, allows us to study their growth conditions, and to assess questions about irrigation and soil fertility maintaining through fertilization and crop rotation practices (Fiorentino et al., 2015). Never performed in France for LBK period, analysis on organic amendments were carried out at Vaihingen-en-der-Enz (Germany) as well as Brzezie 17 and Iwanowice-Klin (Poland). These works suggest a low intake (zero intake/ha) to moderate intake (10-15t/ha) of manure on plots (Bogaard et al., 2013; Mueller-Bieniek et al., 2019). Reference measurements were obtained on manured experimental fields at different rates (Bogaard et al., 2013). A work on the role of manure in the agricultural productivity of mid-20th century, describes more modest manure intakes which could range from 1.5 to 3t/ha (Voisin, 1953). Employment of an organic amendment from animal origin in the Early

Neolithic allows us to propose the hypothesis of a strong agriculture/livestock integration from the first farming systems in western temperate Europe. Its quality depends on the type of animal, their diet and its method of preparation, in a pile or in a pit for example (Brunet and Beuret, 1901). The method of manure preparation, such as its composition and associated structures (pit, pile), is however not known for the Neolithic periods. Additionally, manure can also be gathered on pastureland or deposited when grazing animals on harvested fields.

Concerning the integration of legumes into crop rotation, there is no direct evidence of this practice in the early Neolithic. Legumes, like peas or lentils, fix atmospheric nitrogen and transform it into biological nitrogen. This nitrogen is recycled and serves the rest of the cultivated ecosystem. It is essential during all phases of plant development. The availability of nitrogen in the soil is thus higher for cereals sown after a pea crop by example. The two fertilization methods (manuring, rotation) were therefore tested at the Haute-Île Park.

| Année | Parcelle | Taxon | Fertilisation | Semis | Saison | Surface (m²) | Poids semé (gr) | Poids récolté (kg) | Rendements calculés | | |
|-------------------------------|----------|-----------------------|----------------|---------|-----------|-----------------|-----------------------|--------------------------|---------------------|-------|--|
| | | | | | | | | | ratio | kg/ha | |
| | P1_A | Amidonnier | Sans | Sillons | Hiver | 15,75 | 140 | 1,458 | 1:10 | 926 | |
| Année-test (2017- 2018) | P1_B | Amidonnier | Sans | Volée | Hiver | 15,75 | 150 | 0,763 | 1:5 | 484 | |
| | P2_A | Engrain | Sans | Sillons | Hiver | 15,75 | 100 | 2,315 | 1:23 | 1470 | |
| | P2_B | Engrain | Sans | Volée | Hiver | 15,75 | 150 | 2,076 | 1:14 | 1318 | |
| | P3 | Légumineuses + lin | Sans | Divers | Printemps | 31,5 | ~ | - | - | - | |
| | P4_A | Méture | Sans | Poquet | Hiver | 15,75 | 70 | 0,34 | 1:5 | 216 | |
| | P4_B | Méture | Sans | Volée | Hiver | 15,75 | 150 | 0,372 | 1:2,5 | 236 | |
| | P1_A | Amidonnier | Sans | Sillons | Hiver | 7,87 | 75 | 0,774 | 1:10 | 983 | |
| Année 1 (2018- 2019) | P1_B | Engrain | Sans | Sillons | Hiver | 7,87 | 75 | 0,94 | 1:12,5 | 1194 | |
| | P1_C | Méture | Sans | Sillons | Hiver | 15,75 | 150 | - | - | 122 | |
| | P2_A | Amidonnier | Fumure (2t/ha) | Sillons | Hiver | 7,87 | 75 | 0,322 | 1:4 | 409 | |
| | P2_B | Engrain | Fumure (2t/ha) | Sillons | Hiver | 7,87 | 75 | 1,046 | 1:14 | 1329 | |
| | P2_C | Amidonnier | Fumure (2t/ha) | Sillons | Printemps | 7,87 | 75 | 0 | 0 | 0 | |
| | P2_D | Engrain | Fumure (2t/ha) | Sillons | Printemps | 7,87 | 75 | 0,831 | 1:11 | 1056 | |
| | P3_A | Amidonnier | Rotation | Sillons | Hiver | 15,75 | 150 | 1,084 | 1:7 | 688 | |
| | P3_B | Engrain | Rotation | Sillons | Hiver | 15,75 | 150 | 1,772 | 1:12 | 1125 | |
| | P4 | Légumineuses + lin | Sans | Divers | Printemps | 31,5 | - | - | - | - | |
| | P1_A | Amidonnier | Sans | Sillons | Hiver | 7,87 | 75 | 0,553 | 1:7 | 703 | |
| | P1_B | Engrain | Sans | Sillons | Hiver | 7,87 | 75 | 1,325 | 1:18 | 1683 | |
| | P1_C | Méture | Sans | Sillons | Hiver | 7,87 | 150 | 1,48 | 1:10 | 943 | |
| Annee 2 (2019- | P2 | - | | - | - 2 | - | 12 | 2 | - | 2 | |
| (2019- 2020) | P3_A | Amidonnier | Fumure (2t/ha) | Sillons | Hiver | 7,87 | 75 | 1,276 | 1:17 | 1620 | |
| | P3_B | Engrain | Fumure (2t/ha) | Sillons | Hiver | 7,87 | 75 | 1,041 | 1:14 | 1322 | |
| | P4_A | Amidonnier | Rotation | Sillons | Hiver | 15,75 | 150 | 1,74 | 1:12 | 1105 | |
| | P4_B | Engrain | Rotation | Sillons | Hiver | 15,75 | 150 | 2,091 | 1:14 | 1328 | |

Table 2 – Crop rotation carried out each year with area and weight of sown spikelets. The ratio of the area, weight of sown spikelets and yield obtained on each subplot for the three experimental years. The ratio corresponds to the weight in grams of spikelets harvested divided by the weight in grams of spikelets sown. The calculation in kg per hectare (kg/ha) is given as an indication.

Concerning the quantities of manure to be applied, the choice was oriented towards a weak amendment in order to test the effect on yields and on the isotopic signal (δ 15N) of experimental cereals. The first one year, the manure was composed of a mixture of manure from sheep and Highland cows (1/3 sheep, 2/3 cow) raised without the use of antibiotics on the Park, and exclusively cattle manure the following year. The manure was collected in the spring from the areas of pasture or sheepfold; it was left to decompose into pile near the site mixed with earth and grass or straw, then placed on the plots approximately two to three weeks before sowing (fig. 4B). During the years 1 and 2, approximately eight buckets of manure per plot, corresponding to approximately 80 liters, or the calculated equivalent of 2t/ha, were introduced. Concerning legumes, once the plants are dry, the pea and lentils

plants were pulled out during the test year and cut at the bottom of the stem during year 1 to leave the roots in place.



Fig. **4** – **A**, soil preparation, test year; **B**, manure preparation composed of a mix of cattle dung and straw for the year 2; **C**, sowing in furrows traced with a wooden hoe, year 1; **D**, einkorn, April 2018 (photos: A. Salavert).

Sowing

During the test year, three sowing techniques (furrow, broadcast, poquet) were tested. At sowing time, the weight of spikelets sown per m2 was slightly more important with broadcast method, the poquet method being the most economical (table 2). From the soil preparation point of view and execution speed, the broadcast sowing is easier to implement than sowing in furrows. However, over the next two years, only the furrow sowing technique was used because it offered better yield during the year test (*infra*) and easier to harvesting (fig. 4C and 4D). For each cereal plot, the total grains sown amounts to approximately 10 g per m2 (table 2). Initial seeds provided by J.-F. Berthellot, are varieties sown in the fall (winter crop). Only the autumn sowing was tested during the test year (2017- 2018) and year 2 (20192020). Autumn sowing and spring were tested during year 1 (2018-2019). They took place between the end of October and the beginning November for those in autumn, and mid-May for those in spring 2019.

Harvests and post-harvest processing

There was no visible damage linked to the attack pests such as field mice, birds, mice and rabbits, the latter two having made numerous devastations in experimental fields respectively



Fig. 5 – **A**, emmer stalk lodging at the edge of the plot (P3_A), July 28th, 2020; **B**, ear harvesting with a replica knife (confection: F. Pichon and F. Abbes, UMR5133); **C**, harvested emmer (P1) during the test year - on the left harvested at the ear, on the right harvested at the bottom of the stalk; **D**, threshing of cereals harvested at the bottom of the stalk; **E**, sieving of threshing products (photo: C. Bouchaud), **F**, storage of emmer spikelets after threshing, sieving and sorting of the largest residual straw fragments; **G**, einkorn spikelets remaining on the stalk after threshing (photos: A. Salavert).

of Hambach and Forchtenberg (Lüning et al., 1980; Rösch et al., 2002). At harvest time, lodging was observed during the test year on the plot in maslin, harvested 20 days after the

plots in monoculture, and during year 2 on the edge of emmer plots (fig. 5A). Nevertheless, this phenomenon did not affect yields, because the ears of the affected plants were not damaged and were therefore been harvested. Each year the harvests took place between July 10 and July 30 depending on ears maturity of the two hulled wheats and the availability of the team participating in the implementation of the experiment. No delay in the ripening of einkorn was noted, reputed to be later then emmer. The cereals have been harvested with replicas of Neolithic tools (two sickles and a harvesting knife, fig. 5B). For each plot and half plot, half of the sown area was harvested at the top of the stem, the other half at the bottom of the stem in order to experiment with the different techniques and evaluate the diversity of residual weed seeds in stocks after processing (fig. 5C). Ears not all reaching the same height in a plot, harvesting at the bottom of the stem proved to be faster to implement that the harvest at the top of the stem which forced to harvest ear by ear. Furthermore, with this last method, a second pass is necessary to remove the stubble remaining on the plots. In practice, the simultaneous harvest of several ears having approximately the same height is possible, but not easy to implement. Additionally, for your information, einkorn is very easy and guick to harvest by simply tearing off the whole plant.



Fig. 6 – Weather conditions for the three agricultural years. Surveys from Montsouris-Paris, about 13 km west of the "archéosite" (source: www.infoclimat.fr).

The cereal processing stage consisted of dehusking ears, that is to say to separate the grains from the rachis, before storage. This step was not the subject of a dedicated experimental protocol. Firstly, the cereals were threshed with a straight stick (fig. 5D). The threshing residue was then sieved (4 mm sieve, fig. 5F). Winnowing has only been tested during the test year, but proved difficult to manage in a short period of time. In fact, the gesture technique requires learning including taking into account the force of the wind. In order not to overestimate the weight of spikelets harvested and bias the yields, the largest remaining straw fragments were sorted by hand before storing spikelets in thick paper bags (fig. 5G). The first spikelets at the base of a ripe einkorn ear remains regularly attached at the top of the stem (fig. 5E). These parts were then disarticulated by hand.

Meteorology

The average temperatures were homogeneous for the three agricultural years, with nevertheless, an average 10°C lower in the test year in February compared to in other years (fig. 6). Precipitation totals were variable with, for the three years, July month rather dry and lots of sunshine. Cumulation spring precipitation was quite moderate during year 2 compared to the previous two years. During year 1, the drought of September and October, coupled with strong sunshine, made the soil work very difficult soil in the fall.

METHODS

Yield calculation method

Spikelets were weighed on a kitchen scale electronic after last step of cereals processing (sieving) and before storage. The weighing was carried out on the same day for all the plots, in order to avoid a potential difference in residual humidity in grain. For maslin plot, ears of einkorn and emmer were separated by visual identification before the threshing and sieving stages. Spikelets of two species were then weighed separately. A total of 23.6 kg of spikelets was thus harvested throughout experiment duration (table 2).

The chosen mode of calculation is the so-called "true yield" or "*rendement vrai*" (Paillet, 2005), calculated by dividing the weight of spikelets harvested on the weight of spikelets sown, hereinafter called ratio or yield. The objectives are to observe (1) if there is a dominant taxon (einkorn or emmer) during experimentation in monoculture plots and the plot in maslin, (2) if there are differences in productivity between plots and sub-plots depending on sowing methods for the test year (broadcast, poquet, furrows), soil fertilization methods (manuring, rotation with legumes, without fertilization) and seasonality seedlings for year 1 (fall, spring).

Weed surveys and caracterisation

Qualitative surveys

As part of the experiment, the issues likely to be addressed by the study of weed flora mainly concern cultivation methods. Biological characteristics and ecological requirements of wild herbaceous plants associated with crops can reflect seasonality of sowing, intensity of soil work (depth of plowing, rate of weeding) as well as certain practices such as manuring or irrigation. FIBS (Functional Interpretation of Botanical) approach Surveys, developed by the Sheffield laboratory in England, studies these relationships to interpret the archaeological assemblages (Charles et al., 1997). It connects certain attributes of plants called "functional" or also called "life traits", such as their biological type (e.g., annual, perennial), the period and duration of their flowering, their ability to survive or regenerate guickly under certain conditions. This approach therefore allows, in theory, to characterize the systems of culture (Bogaard, 2004). However, all species weeds present in the fields at the time of harvest are not represented in the carpological assemblages. Different factors come into play throughout of the farming chaîne opératoire which goes from harvest to plants processing before their storage and consumption. Harvesting methods (top of stem/bottom of stem) and post-harvest processing (threshing, winnowing, sieving) will profoundly influence the weed composition each of the stages.

As part of the experiment, several questions have been raised in connection with these methods of interpretation floristic diversity of carpological assemblages. First of all, composition of weed assemblages observed in the plots is it truly representative of the cultivation system? How does this composition evolve at each stage of the operational chain agricultural (harvesting, threshing, winnowing/sieving) and does it remain representative of that recorded on the plots? Which respective parts of the assemblage are linked to initial seed lots (introduction of exogenous weeds) and the flora of the clearing (surrounding

environment)? What evolution we perceive in the composition of the processions as over the years and based on experienced practices?

In fact, exhaustive surveys of each plot could not be carried out (see above). Those carried out on the field, called *in situ*, are qualitative surveys indicating the presence of the plant, without notion of frequency or abundance of weed flora, on the four agricultural plots and the surrounding meadow. They concern wild herbaceous plants in cultivated plots and the meadow. They were carried out in spring and at the beginning of summer of the test year and year 1. Surveys were carried out globally for all plots of cereals during the test year, and more precisely at the scale of each subplot during year 1. However, due to the absence of surveys for year 2, the evolution of the weeds sets composition depending on farming methods cannot be understood. The statements for the first two years were therefore brought together to have more complete information on the plots with cereal on the one hand, and meadows on the other. A botanical description, an herbarium, photos and the use of regional flora (Bonnier and De Layens, 1986; Jauzein and Nawrot, 2011) allowed the taxonomic identification of weeds.

Weed seeds have been identified in samples of the initial batches given by Mr. Berthellot for sowing in the test year. These samples were taken from the batches of einkorn seedlings (100 ml), of emmer seedlings (120 ml) and the two batches making up the maslin (120 ml × 2). Sub-samples of the cereals products (stocks) from cereal processing, differentiated according to harvesting methods (ear, whole plant) and the treatment stages (after threshing, after sieving) were also taken. To date, in addition to initial seedlings, only a sub-sample of harvest products (300 ml) of einkorn plot (P2), broadcast sown and harvested at the bottom of the ear during the test year was treated (Auray, 2020). Let us specify that this sample corresponds to these cereals transformed by winnowing. For these samples, sorting and identification were carried out under a binocular on the archaeobotanical platform of UMR7209 (MNHN-CNRS) with the help of seed collections/ reference fruits available in the lab.

Characters taken into account

The characterization of wild herbaceous plants includes their classification by ecological habitat (Julve, 1998; Jauzein and Nawrot, 2013) and their distribution by biological type, as well as autoecological indicators, which express the requirements of plants in different areas such as light and edaphic humidity (Julva, 1998). This characterization work is based on the analysis of herbaceous taxa identified to the species and a *taxon-valise* (*Trifolium pratense/repens*) which can be analyzed as a species, from the angle of biological type and autoecology.

These two parameters are often used when analysis of archaeological weeds in order, in particular, to understand farming practices (Bouby, 2000). The biological type of a plant (perennial or annual) is the first criterion to evaluate its ability to regenerate after destruction of its aerial part. It is defined by the positioning of its survival organs during unfavorable periods, which will allow him to respond more or less effectively to disturbances in the physical environment or to edapho-climatic stress. The groups of plants more perfected in this respect are the annuals, of which survival relies on seeds buried in the ground, and perennials with deeply buried survival organs (geophytes) or which have vegetative reproductive capacity by rhizomes or stolons, for example.

Germination period (fall or spring) is a character that can be related to the seasonality of sowing. Weeds germinating in fall (winter annuals) are favored by sowing fall, while spring

annuals are by seedlings of the same season. These spring annuals are favored by intense tillage which dislodges short-flowering autumn weeds.

Autoecological indicators make it possible to characterize the environment in which plants develop, as well as the changes occurring in these environments, in particular the increase or decrease in fertility, by through the indicator N which expresses the requirement in soil nutrients, mainly nitrogen and phosphate. Increase may signal amendment of cultivated plot, when a decrease conversely suggests a soil exhaustion.

This characterization work was applied to all surveys, those carried out *in situ* for the meadow and the cultivated plots, as well as those made in laboratory for initial seeds batches and a sub-sample of einkorn stock in P2 (table 3).

The objectives of weed analyzing are to evaluate (1) the origin of weed flora present in the plots (initial sowing, meadow), (2) diversity and the type of weeds present in the plots under a low-intensity agricultural regime, (3) the ratio of taxa annuals and perennials present in a stock subsample, and to what extent this assemblage is representative of the floristic diversity recorded *in situ* on the plots.

RESULTS

Cereal yields

Comparison of sowing methods during the test year and reference values

The test year (2017-2018) aimed to test different sowing methods. There was no employment of fertilization methods. The emmer and einkorn spikelets were each sown on half a plot in monoculture either broadcast, or in furrows, and in winter cropping. Maslin was sown in half-plots either broadcast, or in pockets.

The yields obtained on the half-plots in furrows are higher than on broadcast half-plots for the two wheats grown in monoculture (fig. 7, table. 2). Whatever the sowing method, the yields of einkorn are at least twice as high as those of emmer. The ratio is between 1:13 and 1:23 for einkorn, and between 1:5 and 1:10 for emmer. For maslin, the ratio is overall lower compared to that of monoculture plots, between 1:2.5 and 1:5. The seedlings in pockets are more efficient than those carried out with broadcast, with a ratio twice as high.

The ratios of the test year obtained on the subplot sown in furrows constitute the reference values for einkorn (1:23) and emmer (1:10). These initial values make it possible to evaluate the interannual variability of yields of seedlings in furrows during the experiment, more precisely (1) the behavior of the two wheats on the unfertilized plot and the fertilized plots, (2) the most efficient taxon and yield variabilities.

Inter-annual comparison of cereal yields according to cultivation methods

Firstly, it is a matter of observing the evolution of yields over the three agricultural years on the unfertilized plot (P1) sown in furrows in winter cropping (fig. 8, tab. 2). Between the test year and year 2, we observe a variability of yields for both cereals leading to a drop of 22% for einkorn and 29% for emmer. During the second year of cultivation (year 1), the two hulled cereals exhibit contrasting behavior. If the yield of einkorn falls significantly, that of emmer remains equal to the reference value of the test year.

Secondly, it is a question of comparing the yields of unfertilized plots with those of fertilized plots both in winter and spring cultivation. In winter cropping, emmer yields for the year 2 are higher on the two fertilized plots than on the unfertilized plot (+43% with manure, +32% with rotation). They are even higher than the value of reference obtained during the test year (fig.

8). For einkorn, the half-plot amended on winter cultivation offers a yield slightly higher than that of the plot unfertilized (+10%) only in year 1. For spring crops of year 1, the yield of halfplot of einkorn is slightly less than the values obtained in winter cropping. For the emmer, no ears could be harvested, although the plants were germinated and raised about fifteen centimeters during winter and early spring.

Dominant taxon and interannual variability

If we take into account all the plots in monoculture and all sowing methods, einkorn is the most efficient cereal and this during the three years of experimentation at the Haute-Île Park (tab. 2, figs. 7 and 8). If we only compare the plots sown in furrows (fig. 8), its maximum yield was obtained during the test year without fertilization (1:23) and its minimum yield on the plot in spring cropping during year 1 (1:11). Its yields nevertheless never fall below the bar of 1:10. For emmer, the maximum yields, higher than the reference value, are obtained on the two plots fertilized as a winter crop in year 2 (1:12 and 1:18). The minimum yield is obtained in spring cultivation during the year (1:0). Its general performance is equal to or less than 1:10.

For maslin sown in furrows, the yield was calculated only for year 2. The ratio is slightly less than 1:10. A mixture composed for half of einkorn spikelets, and the other half of emmer was sown. When harvesting, the report is passed with 63% einkorn spikelets and 37% emmer. In the maslin, the einkorn therefore dominates with an average ratio of 1:15 for einkorn versus 1:8.5 for emmer. During year 1, the stock was lost, sorting of einkorn and emmer plants in from the maslin has all the same was carried out on the experimental site. According to a visual estimation, einkorn also seemed to dominate emmer.

Composition and characterization of weed flora

Herbaceous flora present and introduced

Composition of the herbaceous flora around the plots

The surveys carried out in the meadow mention the presence of at least 46 herbaceous taxa (table 3). These are plants from anthropized environments, whose main habitats include meadows, grasslands, wastelands, fallows and ruderal environments. Some species such as Cirsium (Cirsium arvense/Cirsium vulgare) are ubiquitous, while others add the fields to the list of their habitats (such as shepherd's purse - Capsella bursa-pastoris - or even fat-hen -Chenopodium album). Finally, some plants are more particularly dependent on environments and/or forest hedges, such as broad-leaved helleborine (Epipactis cf. helleborine). They are mainly observed at proximity to the wooded edge of the clearing (fig. 9). If most species are heliophilous (L indicator, the more often between 7 and 8), rarer species like the common lampsana (Lapsana communis) or helleborine have lower requirements (L = 4 or 3). The same goes for water needs. Most of plants are mesoxerophilic to mesohydric, i.e., that they only need average edaphic humidity (HE indicator = 4 or 5), but the presence of certain species with greater requirements, such as comfrey (Symphytum officinale) or meadow foxtail (Alopecurus pratensis) suggest the presence of wetter areas than others within the meadow. Finally, the rather high nutrient requirements (indicator N, most often between 6 and 8) indicate good soil fertility in the clearing (fig. 9).

Herbaceous plants noted in the meadow include 41% annuals, of which a little more than half are winter annuals. Perennials therefore represent 59% of species. Among these perennials, the majority do not have vegetative reproduction system and are therefore not very competitive in case of soil disturbance (fig. 10).

| Nom latin | Nom commun | - | · | | 0 | 1 | a 🕅 | Indicateurs autoécologiques | | | |
|------------------------------------|------------------------------------|---------------|-------|------|------------------|--|---------------------|-----------------------------|-------|--------|-------|
| | | elle: iver | 1 | | nné | g Habitat | alque | (Julve, 1998) | | | |
| | | parc 8 d'h | raine | serr | Lot stock a test | | iolog epro | L | т | HE | N |
| | | Toutes | ٩ | Lots | | | Type t ("sans | (1 -9) | (1-9) | (1-12) | (1-9) |
| Achillea millefolium | Achillée millefeuille | x | x | | | Prairies, pelouses, friches | Vivace | 8 | 5 | 5 | 4 |
| Alopecurus pratensis | Vulpin des prés | | × | | 1 | Prairies humides | Vivace* | 7 | 5 | 7 | 7 |
| Anagallis arvensis ssp. foemina | Mouron rouge | | | | x | Cultures, friches, jachères | Annuelle | 7 | 5 | 5 | 7 |
| Anthemis cotula | Carnomille puante | | | × | | Moissons, cultures | Annuelle d'hiver | 7 | 6 | 4 | 5 |
| Avena fatua | Folle avoine | | | × | | Moissons, cultures d'hiver | Annuelle d'hiver | 7 | 6 | 5 | 7 |
| Avena sativa | Avoine cultivée | × | | × | | Moissons, cultures d'hiver | Annuelle d'hiver | 7 | 6 | 5 | 7 |
| Bellis perennis | Påquerette | х | x | | | Prairies | Vivace | 7 | 5 | 5 | 6 |
| Bromus sp. | Bromes | | | x | х | Milieux rudéraux | | | | | |
| Capsella bursa-pastoris | Capselle bourse-å- pasteur | | x | | | Toutes cultures | Annuelle | 7 | 5 | 5 | 7 |
| Cardamine cf. hirsuta | Cardamine hirsute | x | x | | | Cultures, friches, jachères | Annuelle d'hiver | 5 | 5 | 5 | 7 |
| Cerastium glomeratum | Céraiste aggloméré | × | x | | x | Milieux rudéraux | Annuelle d'hiver | 7 | 5 | 6 | 6 |
| Chenopodium album | Chénopode blanc ou album/murale | x | × | × | | Milieux rudéraux | Annuelle d'été | 8 | 5 | 5 | 7 |
| Cirsium <mark>arvense</mark> | Cirse des champs | x | × | | | Cultures sarclées, friches, jachères | Vivace | 7 | 5 | 5 | 7 |
| Cirsium vulgare | Cirse commun | × | × | | | Ubiquiste | Annuelle d'hiver | 8 | 5 | 5 | 8 |
| Cirsium sp. | Cirse | | | × | ľ | 1 | | Î | | 1 | |
| Dactylis glomerata | Dactyle aggloméré | x | x | | | Ubiquiste | Vivace* | 7 | 5 | 5 | 7 |
| Datura stramonium | Stramoine | | x | | | Ubiquiste | Annuelle d'été | 8 | 6 | 5 | 8 |
| Daucus carota | Carotte sauvage | x | x | | | Cultures sarclées, friches, jachères | Annuelle d'hiver | 8 | 5 | 5 | 6 |
| Dipsacus fullonum | Cardère sauvage | x | x | | | Prairies, friches | Annuelle d'hiver | 8 | 6 | 6 | 8 |
| Epipactis cf. helleborine | Epipactis à large feuilles | x | | | | Prairies, friches | Vivace | 3 | 5 | 5 | 5 |
| Galium aparine | Gaillet gratteron | | x | | | Milieux et ourlets fores- tiers | Annuelle d'hiver | 6 | 5 | 5 | 8 |
| Galium cf. mollugo | Gaillet mou | x | | | | Cultures, friches, ja- chères, lisières | Vivace | 8 | 5 | 5 | 6 |
| Geranium dissectum | Geranium disséqué | x | × | | | Cultures sarclées, friches, jachères | Annuelle d'hiver | 7 | 5 | 5 | 6 |
| Fallopia convolvulus | Vrillée faux-liseron | | | × | | Cultures sarclées, friches, jachères | Annuelle d'été | 7 | 4 | 5 | 6 |
| Helminthoteca echioides | Picris fausse-vipérine | x | × | × | x | Milieux rudéraux | Annuelle d'hiver | 8 | 7 | 3 | 6 |
| Herachleum sphondylium | Grande berce | | × | | | Prairies, friches | Vivace* | 7 | 5 | 5 | 8 |
| Hypericum perforatum | Millepertuis perforé | | x | | | Milieux rudéraux | Vivace* | 7 | 5 | 5 | 5 |
| Lactuca cf. seriola | Laitue scarole | | | x | | Cultures, jachères, friches | Annuelle d'hiver | 7 | 5 | 4 | 6 |

Table 3 – Weed composition in the grassland, in the test year and year 1 plots, in the initial seeding lots and the einkorn harvest subsample (P2, fall broadcast seeding). x: presence, *: without vegetative reproduction.

| Lamium purpureum | Lamier pourpre | x | x | | | Cultures sarclées, friches, jachères | Annuelle | 7 | 5 | 5 | 8 |
|------------------------------------|---------------------------------|---|---|-----------|---|--|---------------------|----|------|---|-----|
| Lapsana communis | Lampsane | x | | | | Milieux rudéraux, lisières | Annuelle d'hiver | 4 | 5 | 5 | 7 |
| Medicago lupulina | Luzerne lupuline | x | x | | x | Prairies, pelouses | Annuelle d'hiver | 7 | 5 | 4 | 3 |
| Medicago sativa | Luzerne cultivée | х | x | x | | Prairies, pelouses | Vivace* | 8 | 6 | 4 | 7 |
| Melilotus albus | Mélilot blanc | | x | | | Milieux rudéraux | Vivace* | - | 1.2 | | 14 |
| Origanum vulgare | Origan | | x | | | Pelouses, ourlets, lisières basiphiles | Vivace* | (6 | 5 | 5 | 4 |
| Papaver rhoeas ou rhoeas/dubium | Grand coquelicot | x | | x | x | Moissons, cultures d'hiver | Annuelle d'hiver | 8 | 5 | 5 | 6 |
| Plantago lanceolata | Plantain lancéolé | x | x | | | Prairies, pelouses, friches | Vivace* | 7 | 5 | 5 | 6 |
| Plantago major | Grand plantain | х | x | | | Prairies, pelouses, friches | Vivace* | 5 | 5 | 5 | 6 |
| Poa pratensis/trivialis | Pâturin des prés/ commun | | | × | | Prairies, friches | Vivace* | | | | |
| Poaceae | Céréales sauvages | x | x | | | | | | | | |
| Polygonum cf. aviculare | Renouée des oiseaux | | | x | | Cultures, friches, jachères | Annuelle d'été | 7 | 5 | 5 | 8 |
| Potentilla reptans | Potentille rampante | x | x | \square | | Prairies, friches | Vivace | 7 | 5 | 6 | 6 |
| Prunella vulgaris | Brunelle commune | x | x | X. | | Prairies, pelouses | Vivace* | 5 | 5 | 5 | 6 |
| Ranunculus bulbosus | Renoncule bulbeuse | x | x | | х | Prairies, pelouses | Vivace* | 8 | 5 | 5 | 3 |
| Reseda luteola | Réséda jaunâtre | | x | | | Milieux rudéraux | Vivace* | 8 | 5 | 5 | 3 |
| Rumex cf. crispus | Patience crépue | | x | | | Prairies humides | Vivace* | 7 | 5 | 7 | 8 |
| Rumex cf. obtusifolius | Patience à feuilles obtuses | | x | | | Ubiquiste (friches, jachères, lisières) | Vivace* | 8 | 5 | 5 | 8 |
| Sambucus ebulus | Sureau yèble | | x | | | Ourlets forestiers | Vivace | 7 | 6 | 5 | 7 |
| Senecio jacobea | Sénéçon jacobée | x | x | | | Friches vivaces, prairies, lisières | Vivace* | | 81 A | | |
| Setaria sp. | Sétaire | | | x | | | ĺ | | i i | | |
| Sonchus asper/oleraceus | Laiteron rude/maraî- cher | x | x | | | Cultures sarclées, cultures d'été | Annuelle | 7 | 5-6 | 5 | 7-8 |
| Stellaria media | Mouron des oiseaux | | × | | | Cultures et milieux rudéraux | Annuelle | 7 | 5 | 5 | 8 |
| Symphytum officinale | Grande consoude | | x | | | Prairies humides | Vivace* | 7 | 5 | 7 | 7 |
| Taraxacum spp. | Pissenlit | x | x | | | Ubiquiste | Vivace* | | | | |
| Torilis japonica | Torilis anthrisque | x | x | | | Milieux rudéraux, ourlets forestiers | Annuelle d'hiver | 6 | 5 | 5 | 8 |
| Trifolium pratense | Trèfle des prés | x | x | | | Prairies | Vivace* | 7 | 5 | 5 | 6 |
| Trifolium repens | Trèfle blanc | x | x | \square | | Prairies | Vivace | 7 | 5 | 5 | 6 |
| Trifolium pratense/repens | Trèfie des prés/trèfie blanc | | | | x | | | 7 | 5 | 5 | 6 |
| Verbena officinalis | Verveine officinale | | × | | | Milieux rudéraux (friches vivaces) | Vivace* | 8 | 6 | 5 | 7 |
| Veronica arvensis | Véronique des champs | x | x | | × | Cultures, friches, jachères | Annuelle d'hiver | 7 | 5 | 5 | 6 |
| Veronica chamaedrys | Véronique petit-chêne | x | x | | | Ourlets forestiers | Vivace* | 6 | 5 | 5 | 5 |
| Veronica persica | Véronique de Perse | х | x | | | Cultures, friches, jachères | Annuelle | 7 | 5 | 5 | 7 |
| Vicia sativa ssp. vegetalis | Vesce des moissons | x | x | | | Cultures et milieux rudéraux | Annuelle | 8 | 6 | 5 | 8 |

Table 3 (continuation) – Weed composition in the grassland, in the test year and year 1 plots, in the initial seeding lots and the einkorn harvest subsample (P2, fall broadcast seeding). x: presence, *: without vegetative reproduction.



Fig. 7 – Comparison of yields (weight of spikelets harvested/weight of spikelets sown) in the test year (20172018), winter crop, without fertilization.



Fig. 8 – Comparison of yields obtained on the unfertilized ("sans"/without) and fertilized ("fumure"/manure, rotation) plots, sown in furrows, in winter (H) and spring (P) crops, during the three agricultural years.

Composition of the herbaceous flora in the initial batches

In the initial seed lots, 18 taxa were identified, 15 of which could be identified to the species (table 3). These taxa include messicole weeds (i.e. fall or winter germinating plants in cultivated areas) such as stinking chamomile (*Anthemis cotula*), garden poppy (*Papaver rhoeas*), cultivated and wild oats (*Avena sativa* and *Avena fatua*), weeds of hoed fields or ubiquitous (*Chenopodium album, Fallopia convolvulus, Polygonum aviculare*), and ruderal or meadow species which have often field as secondary habitat (such as *Lactuca serriola* and *Lathyrus hirsutus*). The distribution of the 15 taxa according to their biological type reports 11 annuals (73% of the total taxa) of which two thirds are winter annuals, and 4 perennials (27% of the total). This distribution is probably quite close to that of the weed flora actually present in the fields where the cereals were harvested. According to Jauzein and Nawrot (2011), in cultivated areas currently, we observe on average 20% perennials and 80% annuals. Cereals grown by J.-F. Berthellot were carried out in autumn sowing, this which probably also explains the presence of a majority of winter annuals among the weeds of the initial batches.

The presence of a few summer weeds may have been favored by the practice of rotations led by J.-F. Berthellot (summer vegetables).



Fig. 9 – Main auto-ecological parameters of weeds identified in the meadow, plots and einkorn stock subsample. Prairie= meadow; Parcelles= plots.

Herbaceous flora in cultivated plots and einkorn stock

A total of 36 herbaceous species were observed in cereal plots (table 3). Most (n=25) are species noted in the meadow (fig. 11). At least 5 taxa may originate from the prairie and/or seedlings and 2 taxa identified to the species come exclusively initial seedlings (*Papaver rhoeas* and *Avena sativa*). *Lapsana communis* and *Epipactis* cf. *helleborine*, both recorded in the plots have no origin identified. It is possible that they were present but have not been identified in the prairie due to their low occurrence for example or that they have not been in flower at the time of the surveys.

In the plots, the main autoecological classes weeds noted *in situ* are shown (fig. 9). Distribution by biological type reports 50% annuals, three quarters of which are winter annuals, and 50% perennials of which the majority are perennials without reproductive organs vegetative (fig. 10).

Comparison with meadow and initial seed lots leads to the following observations. In terms of distribution by biological type, the spectrum observed in the plots is quite close to that observed in the meadow, with nevertheless a slightly lower rate of perennials, and in particular perennials without reproductive organs vegetatively.

In the einkorn stock after threshing and winnowing the plot (P2, broadcast, harvest at the bottom of the stem), 10 taxa were identified to the species (table 3). This is a subset of the spectrum present in the plots. The distribution by biological type indicates 80% annuals, which are essentially winter annuals. From perennials, those without vegetative reproduction dominate (20% of the total) (fig. 10). The observed annual/perennial ratio in the stock is therefore not representative of what has been observed on the plot. Comparing the stock with the survey of cereal plots shows a higher rate of annuals.



Fig. 10 – Distribution of biological type of herbaceous weed taxa in the different surveys.



Fig. 11 – Distribution of herbaceous taxa found on cereal plots according to their origin.

Summary

The short duration of the experiment (3 years), the crisis health of spring 2020 and the loss of the maslin harvest of year 1 do not allow to assess the reproducibility of the first results obtained on yields and development of weed flora according to cultivation methods at the Haute-Île Park.

Nevertheless, significant results seem to emerge of experimentation. The furrow method offered a better yield than broadcast or pocket sowing during the test year. Einkorn is the most efficient cereal at the Haute-Île Park as well as on the plots in monoculture than in meterage. The average yields for einkorn is 1:15, while it is 1:8.5 for emmer. The yield is always greater than 1:10 for einkorn whatever the seasonality of sowing and fertilization methods. For emmer, the ratio is generally less than 1:10. Concerning the seasonality of sowing, spring cultivation tested during year 1 is less efficient than winter cultivation for both taxa, emmer having even stopped its development during the agricultural season. For plots sown in furrows, the yields, for both cereals, present interannual variability but also intraannual one. According to years, the ratio goes from 1:7 to 1:17 for emmer and 1:12 to 1:23 for einkorn in winter cultivation.

On the unfertilized plot, the evolution of yields between the test year and year 2 is discontinuous. The two cereals exhibit contrasting behaviors. For einkorn, the plot cultivated without fertilization during of the test year delivered the highest return of three years of farming. On the five fertilized plots in monoculture, yields are not systematically higher than on unfertilized plots. For emmer, two plots cultivated during the year 2 still delivered a return higher than the unfertilized plot and even at the reference value of the test year.

Regarding weed surveys, the signal from the fertilization can be difficult to assess due to the inherent fertility of the clearing's soils and the short duration of the experiment. The assemblage identified in the sub-sample of einkorn stock is reduced compared to the diversity recorded in the plots. Annuals, particularly those associated with winter crops, make up the majority of the harvest. The grains and capsules of garden poppy arrived on the plots via initial sowing. The rest of the taxa are plants found in the meadow near the plots. The distribution by biological type of herbaceous plants presents in the cultivated plots shows a gradient which moves away from the meadow composition to go towards a more typical procession of cultivated areas without reaching the perennial/annual ratios that we observe today in the fields (Jauzein and Nawrot, 2013). The annual/perennial ratio observed in the stock subsample does not reflect that observed in the plots.

DISCUSSION

The discussion will focus on the results that seem the most relevant to be put into perspective with archaeobotanical data: (1) the best performance of einkorn, (2) the relative inefficiency in the short term of fertilization practices tested (manuring, rotation with legumes) in terms of yield, (3) ratio of annual versus perennial weed taxa in the plots and in a stock sub-sample of einkorn under a less intensive agricultural regime.

Better einkorn performance

Einkorn and emmer are both famous as being hardy wheats, adapted to little fertile soils. They grow today in marginal areas, unsuitable for modern naked wheat monoculture (Martin and Leighty, 1924; Stallknecht and al., 1996; Zohary et al., 2012; Mascher et al., 2017). According to the results of current and early 20th century agronomic experiments in North America, emmer generally seems to have a better productivity than einkorn (Martin and Leighty, 1924; Troccoli and Codianni, 2005; Kreuz, 2007; Masher and al., 2017). These experiments take certainly place in other climatic and environmental contexts and use technical means very different from those employees at Haute-Île Park. However, the domination of emmer on einkorn is observed on the same station and with comparable cultivation methods. Likewise, in the Neolithic farming experiment of Hambach carried out on slash and burn (Lüning et al., 1980), the returns extrapolated from the year 1979 (i.e. that a correction factor was applied due to mice attacks based on stocking density before the ears rise and the number of stems actually harvested), in spring sowing, are clearly higher for emmer (652 kg/ha, ratio 1:12) by compared to einkorn (160 kg/ha, ratio 1:5).

At Haute-Île Park, einkorn generally offers a better yield during the three agricultural years in monoculture plots. Likewise, einkorn spikelets take over those of emmer in the harvested products on the half-plot in maslin, grown without fertilization. Furthermore, the only experiment spring sowing carried out at the Parc de la Haute-Île by hulled wheat sowing in spring during year 1 delivered zero results for the emmer and a yield of 1056 kg/ha (1:11) for einkorn. How explain the dominance of einkorn in the Haute-Île Park while the emmer seems more productive according to agronomic and experimental experiments?

Emmer is vulnerable to lodging, favored by the size of its stem, generally longer than that of einkorn (Kreuz, 2007; Mascher et al., 2017). The phenomenon of lodging was observed at the time of harvest at Haute-Île Park. It seems to have touched emmer, but also more occasionally einkorn, locally, at the edge of the plot. The lodged emmer and einkorn ears were also harvested therefore not *a priori* impacting the final yields. Likewise, on an agronomic experiment in Switzerland (2014), lodging was quantified in a more pronounced manner on emmer plots whose yields nevertheless remained in the majority, for all varieties (Mascher et al., 2017). Einkorn varieties sown in the Haute-Île Park (a variety in monoculture, two varieties in maslin) are perhaps better suited to the climate and local edaphic conditions that those of emmer, knowing that the original seeds come from the southwest of France. This hypothesis unfortunately cannot be argued more precisely, the reproducibility of this result cannot be verified over the long term. Nevertheless, it is necessary to note that einkorn can be more efficient on soils with high inherent fertility, and under a low-intensity system farming, such as that experienced in Haute-Île Park. *Effects of agricultural practices on cereal yields*

One of the objectives of the experiment was to test several sowing methods and applying different fertilization techniques (without, rotation, amendment) and in particular to compare the yields of the plots fertilized and unfertilized.

Furrow sowing is more efficient in terms of yield than broadcast and/or pocket sowing for the two cereals and the maslin, as has already been mentioned by several authors (Reynolds, 1979; Sigaut, 1992). The main reason is that before the invention of harrow, the broadcastsown grains are not sufficiently covered to protect them from predators, such as the birds.

On the plot without fertilization, cereal yields are irregular, even if they have generally decreased to the end of the three experimental years (between 20 and 30% decrease). Similarly, at Butser Farm, the yield of emmer, grown without amendment, does not show decrease, but significant variability during the 14 years of experimentation (Reynolds, 1992). At the Haute-Île Park, the overall drop in yields cereals observed between the test year and year 2 can be due to a decline in soil fertility and competition weeds or, more cautiously, be due to the interannual variability of yields.

On plots having benefited from fertilization, the results are mixed. For einkorn, the values are most often lower than those obtained on the unfertilized plot. For emmer, the yields are higher on fertilized plots than on the unfertilized plot in two cases, during year 2. The best performance was achieved on the plot (P3) having benefited from a succession of methods of fertilization. This result allows us to pose the hypothesis of fertilization benefit in the short term, or at least, of a better response from emmer to fertilization techniques succession. Indeed, organic amendment increases soil fertility over time (Bogaard, 2012). Duration of the experiment of the Haute-Île Park did not make it possible to verify this assumption. However, other factors such as excess or water deficiencies, or even sunlight can take into account the strong interannual variability yields which are systematically observed on agronomic experiments or ethnobotanical observations for these two hulled cereals (Hajnalová and Dreslerová, 2010; Mascher et al., 2017; Herrera et al., 2020). This is well illustrated by an experiment long-term carried out in Switzerland on cereals winter modern. The authors concluded that in low-input agricultural systems, the impact of factors environmental factors on the variance of yields is high (Herrera et al., 2020). At Haute-Île Park, during of year 2, the plots seem to have benefited from a higher number of hours of sunshine associated with a lower cumulative precipitation than during the two previous years. However, if we consider that the environmental conditions may have played a role in the performance of the emmer plant on two half-plots, they did not significantly benefit einkorn, nor to the emmer on the plot without fertilization during of year 2. As a hypothesis, we propose that the succession of fertilization methods associated with favorable weather conditions were able to participate to the success of the emmer plant during the last year of experimentation.

Weed flora

Emmer and einkorn were competitive facing herbaceous weed plants, with the exception of emmer plot sown in spring, which did not been at the end of its development.

The spectrum observed in the plots is quite close from that observed in the meadow, with the following differences: a slightly lower rate of perennials and in particular of perennials without reproductive organs by vegetative way. These differences are probably explained by the fact that these perennials are very uncompetitive in disturbed soils. Even if the farming system practiced at the Haute-Île Park was not intensive, it probably enough to permanently dislodge a certain number of herbaceous plants poorly biologically equipped for fast regeneration.

The perennial/annual ratio in cultivated plots is still quite far from what we observe in the current fields (Jauzein and Nawrot, 2013). Besides the low intensity of tillage which contributes to accentuate the balance in favor of perennials, the difference can be explained by the fact that the plots were cultivated only two years. Even if the initial environment was different in the Hambach forest (woodland), some results of the experiments carried out there

have shown that annuals take some time to settle when planting crops. In Hambach, it took six years for the rate of annuals to supplant that of perennials (Bogaard, 2004).

The strong dominance of winter annuals in plots and stock reflect the sowing seasonality, as well as the fact that there was no (or little, on the one occasion spring sowing of year 1) tillage in spring which could have dislodged them. On the other hand, in the sub-sample of einkorn stock, the ratio of perennials/ annual does not reflect the ratio recorded in the plots.

This could be due to the fact that annuals, such as garden poppy or bromes, produce more seeds than perennials and are therefore more likely to be present in the samples.

Results of the experiment to the light of archaeobotanical data

The results from the experimentation of the Haute-Île Park allow us to discuss certain archaeological hypotheses to the light of the practical experience of low-intensive subsistence cereal farming. According to a comparative analysis of archaeobotanical assemblages on LBK sites in the province of Hesse (Germany) and Middle Belgium, an east/west partition is noted in the einkorn/emmer ratio between the Rhine region (einkorn) and the Meuse (emmer) whatever the type of anatomical elements (grains, glume bases) taken into account (Salavert, 2011). The argument for a better resistance of einkorn to heavy precipitation was proposed to explain the choice of this cereal in Hesse despite its supposed lower productivity compared to emmer (Kreuz, 2007). This resistance would have allowed for einkorn to be better adapted to higher precipitations which characterize the second half of the 6th millennium BCE, i.e., LBK period (Dubouloz, 2008). The results obtained at Haute-Île Park show that currently, on soil with high inherent fertility, some einkorn varieties may be more efficient than emmer, several consecutive years, under a low-intensive farming system in winter cropping.

Weed assemblages identified on Haute-Île Park's experimental plots are probably enough distant in terms of composition from that characterizing Early Neolithic farming system. Some taxa, such as Chenopodium album, Fallopia convolvulus, Bromus spp. and Lapsana communis, are still found in both types of recordings, archaeological and experimental ones (Knörzer, 1971; Bogaard, 2004; Bakels, 2009; Kreuz and Schäfer, 2011). The weed composition of harvest subsample is interesting to discuss because it is the main source of weed remains in archaeological context. At Haute-Île Park, the subsample of einkorn harvested at the bottom of the stem represents only a quarter of the diversity recorded in situ in the plots, knowing that the seeds were not charred, weeding minimal and pre-storage processing techniques less than optimal. The composition of this sample does not reflect the distribution of herbaceous taxa by biological type observed on the plots. It will certainly be necessary to study more samples to obtain statistical representativeness of the results. In addition, garden poppy (Papaver rhoeas) absent from the meadow during the test year was introduced via the batch of initial seeds, during the test year. The taxon was then developed massively during year 1 and 2 in the plots and their surroundings. This illustrates the ability of certain weeds, here a winter annual plant, absent from the initial environment to quickly integrate into local agricultural biodiversity following the transmission of exogenous cereal seeds. This phenomenon, due to contacts or intercultural exchanges over long distance, allowed many archaeophytes to disperse in Temperate Europe with Neolithic cultivated plants (Pyšek et al., 2005; Brun, 2009).

CONCLUSION

The Haute-Île Park experimentation produced results from practical experience of subsistence agriculture. It made it possible to test a system involving low tillage, moderate

fertilization and no weeding after sowing on permanent cultivated plots sown with einkorn and emmer for three successive years (2017-2020). This type of system allowed, with current varieties sown in the fall in furrows, to harvest on average, 1350 kg/ha of einkorn and 900 kg/ha of emmer per year (the average surface area of the subplots is 11 m2). However, this average must be qualified due to the interannual variability of yields for two two cereals. In the case of the Haute-Île experimentation, einkorn has proven to be the most efficient, even if the emmer seems to respond a little better with the succession of fertilizations on a short term. Analysis of carbon isotopic composition (δ13C) and nitrogen (δ15N) of experimental cereal grains, in progress, will make it possible to assess whether the fertilization signal, particularly nitrogen, is present in experimental cereal grains. Weed assemblage present in one of the stock sub-samples represents a quarter of the taxa actually observed on the plots and that biological types represented do not reflect those recorded in situ. In practical terms, the experiment carried out at Haute-Île Park showed that the plots having benefited from a rotation with legumes are much easier to work in the fall than the plot having not benefited from any rotation and this, from the second year of implementation. Without rotation, weeds settle and soil becomes increasingly more difficult to work, making the practice of crop rotation essential in the long term. The yields and assemblage of weeds from pulse plots and flax have not been studied mainly due to the time that the experimental team could dedicate to the experiment implementation. Their cultures nevertheless found all their meaning in the framework of the practice of crop rotation and promotion of plots to the general public.

From an implementation point of view, farming experiment requires dedicated staff, this from which that of the Haute-Île Park did not benefit. The low return on investment in terms of scientific production in the short and medium term does not favor establishing an administrative and research framework essential to the realization of such a project. However, information obtained from this type of scientific project are fundamental to our understanding of ancient farming systems. For example, the data from Hambach forest experiment, carried out in the 1980s, contributed to the characterization of the pioneering farming system from temperate Europe, 20 years later, showing all the interest in leading this type of long-term experimentation.

See the original paper for acknowledgments and references

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